NAIC-ID(RS)T-0058-96

NATIONAL AIR INTELLIGENCE CENTER

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by

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HUMAN TRANSLATION

NAIC-ID(RS)T-0058-96 14 March 1996

MICROFICHE NR: 96C000236

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English pages: 9

Source: Cama, China Astronautics and Missilery Abstracts, Vol. 2, Nr. 4, 1995; pp. 1-4

Country of origin: China
Translated by: SCITRAN
F33657-84-D-0165
Requester: NAIC/TASS/Scott D. Feairheller
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ABSTRACT

A low orbit satellite constellation which only provides navigation and positioning services for a certain specially designated region is capable of achieving the functions of global positioning systems. This system may possibly be what most nations hope for. Preliminary results show that, if it is desired to satisfy this requirement, there is a need for a satellite constellation composed of 27 low orbit satellites in five respective orbital planes in order to provide regional navigation and positioning services. From research associated with this article, it is proven that the concept of a regional positioning system formed from a low orbit satellite constellation is feasible. Although the number of individual satellites required is not necessarily a lot fewer compared to original global positioning systems, due to the low orbit satellites, however, delivery energies required by the satellites are, by contrast, much less compared to synchronous orbit satellites. This point should be an advantage which making use of low orbit satellite constellations to provide navigation and positioning functions can achieve.

I. FORWARD

The Global Positioning System, GPS, is already in wide spread application. However, the satellite constellation which supplies this function, is, by contrast, NAVSTAR, which is composed of twenty four geosynchronous satellites. Moreover, on the basis of the position and distance from a specially designated point of four satellites in the air above this point, it is then possible to very accurately calculate out the position of this specially designated point. However, the costs of launching synchronous satellites are very high. In conjunction with this, they are certainly not ones most countries are capable of undertaking. Besides this, the requirements of navigation and positioning should only be limited to a certain specially designated region. To say it another way, if one only considers the navigation and positioning requirements associated with a certain region, there is then certainly no need to set up a system similar to NAVSTAR. A satellite constellation which is only capable of supplying naviagtion and positioning functions for a certain specially designated region can be hoped for by most nations.

Due to advances in electronics technology, small scale satellites (LightSats) are made able to undertake even more tasks. We are then capable of developing LightSats constellations even more (unclear) economically than in the past in order to undertake different missions. Besides this, due even more to developments in launching delivery vehicles, we are able to launch low orbit (Low-Earth Orbit, LEO) satellites even more econonically than in the past. Therefore, the design of satellite constellations associated with low orbits is receiving more and more serious attention by the day [1-6]. This article puts forward a new (unclear) concept: not using geosynchronous satellite constellations any more to act as navigation satellites but to use low orbit satellite constellations to act as navigation satellites. Due to the fact that low orbit satellite constellations are only capable of providing partial regional coverage, it is also only possible to supply navigation and positioning functions for a certain specially designated region. Therefore, Regional Positioning System, RPS, is then taken (unclear) as its designation. Low orbit satellites refer to orbits with altitudes of 500 to 2000 km. They go around the earth 11 to 15 times each day. The U.S. Navy Navigational Satellite System, also designated as the TRANSIT system, includes six satellites in circular polar orbits (1100 km). In the same way, they also provide positioning functions. However, due to the fact that the time interval associated with each satellite going through a certain point is 90 minutes, it is, therefore, not possible to achieve accurate positioning functions. If use is made of this low orbit satellite constellation to provide accurate navigation and positioning functions, then, in the space above a certain specially designated region, it is necessary to

have at least four of the satellites in this satellite constellation appear. That is also nothing else than this artificial satellite constellation providing, with regard to this specially designated region, coverage required for continuous time periods. Moreover, it is necessary to satisfy the number requirement for four satellites. The purpose of this article lies, therefore, in putting forward designs of satellite constellations associated with the satisfying of this coverage requirement. Moreover, as an example, the region formed by Taibei, Beijing, and Chongqing will be used as this specially designated region.

Reference [6] applies the methods of low orbit satellite constellation design completed in Reference [5], carrying out satellite constellation designs associated with passing through two observation points. Reference [7] then carries even a step further the expansion of satellite constellation design to a specially designated region. In order to make design procedures simple, this specially designated region is covered making use of three reference points. Based on applications of Reference [7], this article, therefore, will first of all design requirements related to Time Gap, making further changes for the sake of continuity requirements. That is also nothing else than requiring time gap requirements to be zero. Going even a step further, in order to satisfy positioning requirements, in the air above this specially designated region, at least four satellites must appear at the same time.

In the section below, it will then be possible to provide an explanation of orbit altitudes associated with satellite constellations for this coverage requirement. Only then a selection is subsequently made of other orbital parameters. In Section IV, the example discussed above will then be used to put forward design results. Section V is then discussion and recommendations. /2

II. SATELLITE CONSTELLATION ORBIT ALTITUDES

Characteristics of a satellite constellation are determined by the orbital parameters of satellites composing this satellite constellation. Therefore, design of satellite constellations should be better understood if one begins with these six orbital parameters. As was discussed before, satellite constellations belong to low orbit satellites. However, it is still necessary to satisfy the conditions of being able to cover this region. Therefore, satellite orbit altitudes must then satisfy a number of limiting conditions. Assume that this region can be covered as a certain specially designated point Po and a geocentric angle β (refer to Fig.I). h is orbital height. Re is the radius of the earth. σ is the minimum angle of elevation required. Then, the relationship of the various quantities discussed above can be expressed by the equation below:

$$\beta = \pi/2 - \sigma - \sin^{-1}[R_e \sin(\beta + \pi/2)/(R_e + h)] \qquad (1)$$

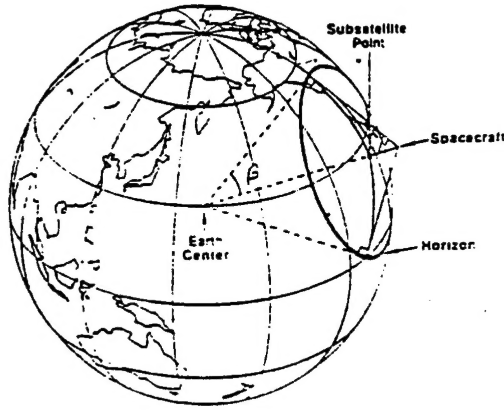

Fig.I Geocentric Angle and Coverage Region

From Fig.I, we can discover that, if it is necessary to cover this region, then, the minimum angle of elevation σ must be greater than or equal to σ. In equation (1), using β to subtitute in for the minimum angle of elevation required σ on the right side of the equal sign--after going through simplification--one solves for orbital heights as in equation (2). Therefore, satellite constellation orbital altitudes must then be at least larger than what is obtained in equation (2).

$$h = R_e\left[\frac{\cos\beta}{\cos 2\beta} - 1\right] \qquad (2)$$

Besides satisfying coverage requirements, this article opts for the use of (unclear) Repeated Ground Track (unclear) orbit satellite constellations. Therefore, orbital hemi major axis a (unclear) must also satisfy (unclear) conditions set out below (unclear)

$$f(a_0) = \frac{N_{rep}\omega_e}{\sqrt{\mu}} a_0^{3/2} - (k_1 - N_{rep}k_2)a_0^{-2} + N_{rep}k_1k_2a_0^{-4} - 1 = 0 \qquad (3)$$

In equations

$$k_1 = \frac{3}{2}J_2R^2\left(1 - \frac{3}{2}\sin^2 i\right)$$

$$k_2 = \frac{3}{2}J_2R^2\cos i$$

In the equations above are the number of iterations associated with satellites going around the earth in circular orbits each day. With regard to given orbital angles of elevation, on the basis of these equations, it is then possible to very easily solve for satellite orbit hemi major axses associated with repeated ground tracks. As far as orbital hemi major axses solved for from equation (3) are concerned, if they also satisfy height limitation demands associated with equation (2), then, altitude hemi major axses associated with satellite constellations can be determined. Due to our opting for the use of circular orbits, orbit eccentricities are, therefore, zero. Having determined orbital hemi major axses and eccentricities, in the section below, a selection is then made with regard to other orbital parameters.

III. OTHER ORBITAL PARAMETERS

In Reference [5], we discovered that if orbital angles of inclination are smaller than $\phi-|\beta_1|$ (refer to Fig. II), then, artificial satellites do not produce coverage with regard to this point. If angles of inclination are between 90° and $\phi+|\beta_2|$, this observation point is still capable of seeing this satellite. That being the case, due to the cause of high inclination angles, we do not opt for the use of this inclination angle interval. Therefore, the range of inclination angles is between $\phi|\beta_1|$ and $\phi+\beta_2$. Due to opting for the use of circular orbits, the true anomoly of orbits is, therefore, equal to mean anomaly. /3

Table I Actual Design Example

(1) 衛星组	(2) 軌道半長軸 (Km)	(3) 衛星個數	(4) 軌道傾角 (deg.)	(5) 升交點	(6) 初始平均近點角
1	8480.275	7	35	180.10.226.476,272.851, 319.2[illegible]6,5.601,51.976, 98.351,	0.,209.877,59.753, 269.631.119.508.329.385, 179.261
2	8481.450	5	37.5	32.966,184.433.335.900, 127.366,278.832	0.133.867,267.734, 41.601.175.468
3	8482.703	5	40	32.969.184.340.335.713. 17.085,278.457	0..134.906.269.812. 44.717,179.623
4	8484.034	5	42.5	32.971.90.788.148.605. 206.421,264.238	0..84.015.168.030. 252.045.336.061
5	8485.444	5	45	32.973.90.72.148.591. 206.400.264.208	0..84.102.168.205. 252.307.336.410

Key: (1) Satellite Constellation (2) Orbital Hemi Major Axis (3) No. of Satellites (4) Ascending Node (5) Initial Mean Anomaly

Moreover, in satellite constellations, the anomaly of the first satellite is assumed to be zero. Besides this, we do not consider the actual time period associated with artificial satellites crossing through this region. Therefore, the time of the first satellite in satellite constellations crossing through perigee is also assumed to be zero.

The orbital parameters discussed above only refer to satellites in the same orbital plane. Due to the fact that this article is about trying to select satellite constellations that possess positioning functions, orbital planes of this satellite constellation will, therefore, not be limited to one. Moreover, as far as satellites in the same plane are concerned, their interval as well as time of appearance in the space over a certain region will then be determined by a requirement with regard to positioning. This requirement will be that the time period of remaining in the space above this region should be

greater than the time interval between satellites. This requirement then also limits the height of satellite constellations.

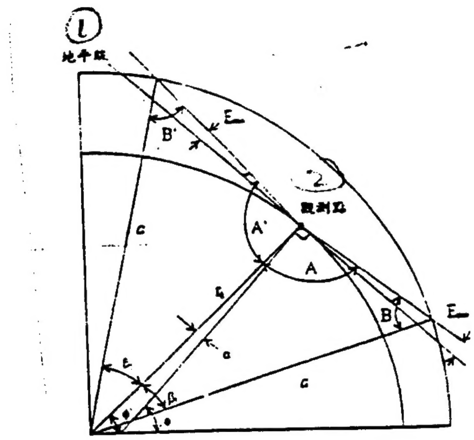

Fig.II Regions Visible to Satellites on Observation Point Meridional Planes

Key: (1) Horizon (2) Observation Point

IV. DESIGN RESULTS

The latitude and longitude coordinates for Taibei, Beijing, and Chongqing are, respectively, 25.07°N, 121.54°E; 39.93°N, 116.42°E; and, 29.58°N, 106.50°E. Using the point 31.15°N, 114.85°E as center as well as a geocentric angle of 8.5°, it is possible to cover this region. Table I is a satellite constellation associated with a regional positioning system to cover this region. The ascending node parameters, anomalies, as well as related orbital parameters associated with each satellite are all shown. A total of 27 satellites are used. Fig.III is the Time Line associated with this satellite constellation. The so called Time Line just refers to the time period when satellite constellations are visible from observation points. The left end of each line section is satellite rise time. The right end is set time.

From Table I, we understand that there are a total of five orbital planes associated with this satellite constellation. The lowest angle of inclination is 35°. Next are, respectively, 37.5°, 40°, 42.5°, and 45°. Besides having seven satellites on an orbital plane associated with an angle of inclination of 35°,

in the remaining orbital planes, there are then five satellites each. From the time lines of Table III, it is possible to see that, on each orbital plane, the time interval associated with each satellite is, in all cases, smaller than half an hour. Moreover, the time periods remaining in the space are then greater than half an hour in all cases. At the same time, it is possible to very clearly see that, within any single period of time, there are four satellites in the space above this region. This result should be capable of satisfying the requirements of positioning systems. /4

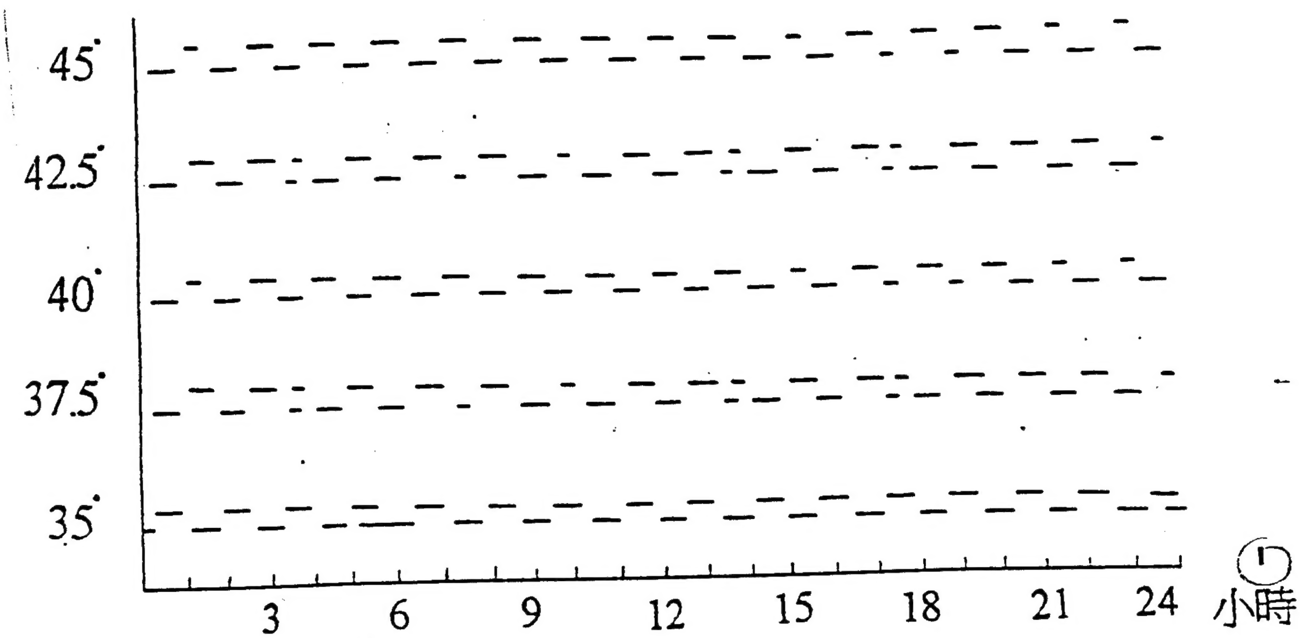

Fig.III Satellite Constellation Time Lines

Key: (1) Hour

V. CONCLUSIONS

In the previous section, we certainly did not eliminate differences associated with selecting the most appropriate orbital angles of inclination. Therefore, the results obtained were certainly not optimum satellite constellations. Differences associated with orbital angles of inclination should be determined by the angle needed between satellites to reach located targets and ground reception stations. Besides this, satellites in the same plane should also be limited by this

angle. In this article we have not then eliminated investigations of this problem. However, using satellite constellations possessing this altitude, the regions they are able to cover are not only such ones as the region postulated in this article. Using this reference point as center, they are able to cover regions with radii of 2500 km. The purpose of this article lay only in attempting to explain that the satellite constellation associated with this so called regional positioning system can be achieved. In future, investigations will continue into the optimization of this satellite constellation design as well as the questions it raises.

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